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Title: Chlorine Worth Study in Support of PF-4 Operations

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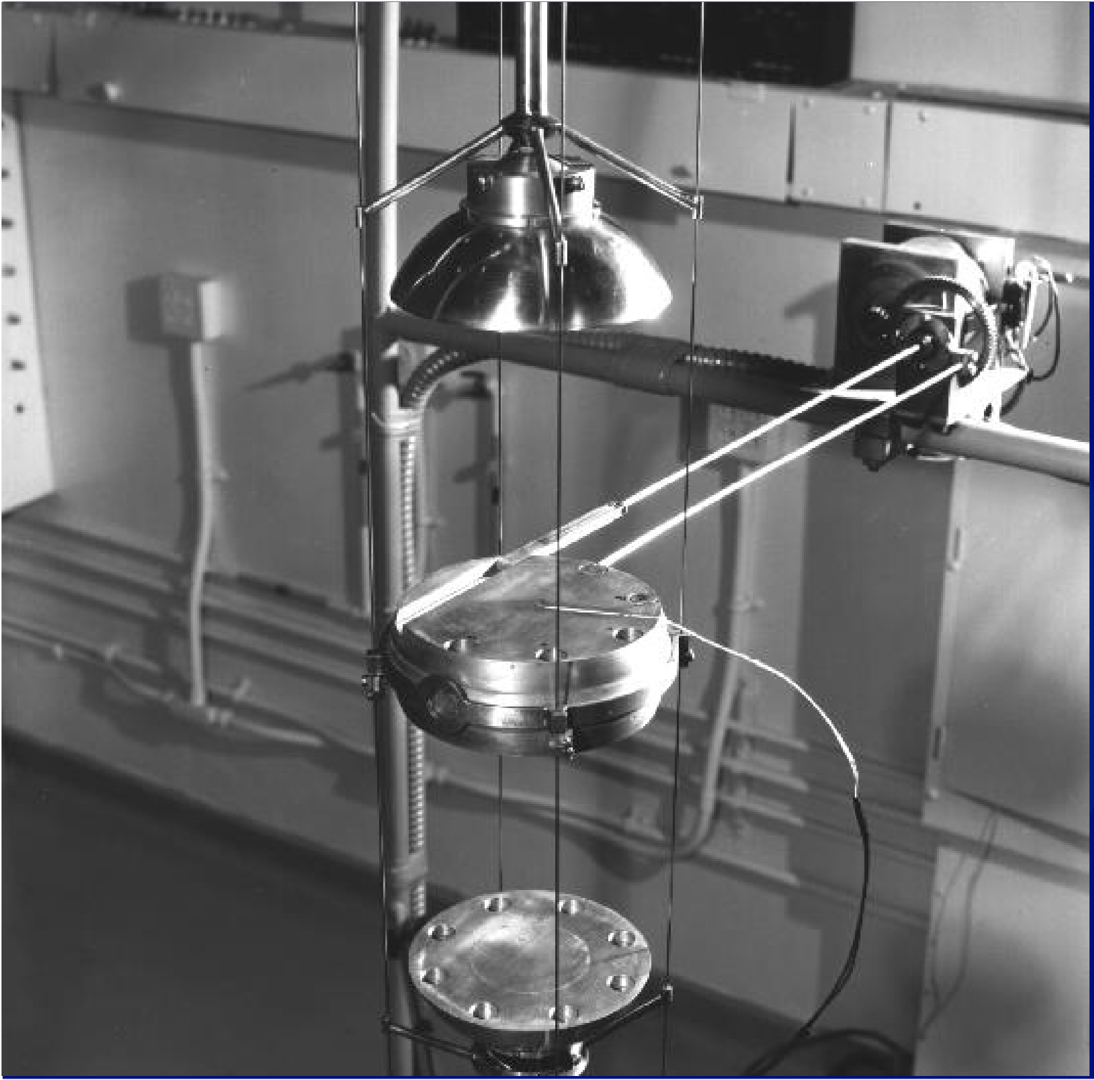

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Chlorine Worth Study in Support of PF-4 Operations

Theresa Cutler, Travis Grove, Jesson Hutchinson, Kelsey Amundson, Nick Wynne, Travis Smith

February 2022

Motivation

- Aqueous Chloride Operations at PF-4 are important:
  - Recover Pu from other processes
  - Reduces waste sent to WIPP
  - Increased throughput for Am production
- Aqueous Chloride Operations have very conservative mass limits (~520 grams Pu)
  - Significant amounts of Chlorine but calculations not crediting Cl-35 neutron absorption
  - Accounting for Cl-35 absorption leads to higher mass limits
- Can experiments be designed/conducted to provide technical justification to NCS in order to increase mass limits?

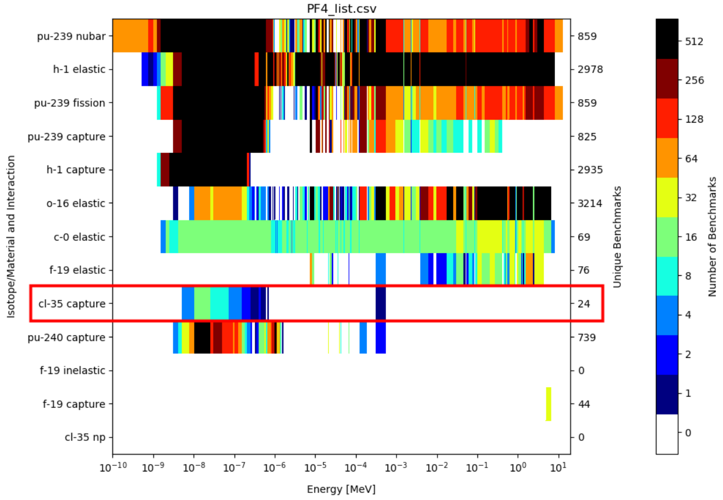
Timeline (VERY FAST)

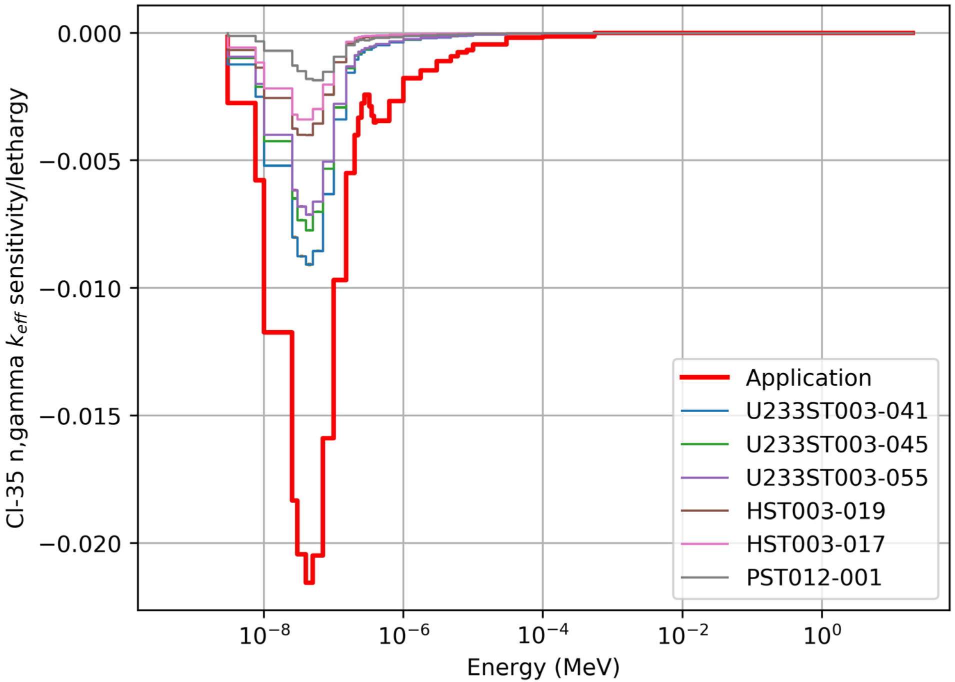
- Initial tasking: June 2020
- Preliminary Design Complete (CED-1): November 2020
- Final Design Complete (CED-2): March 2021
- Part Receipt and Inspection Complete (CED-3a): October 2021
- Experiment Execution (CED-3b): December 2021
- Experiment Documentation Write-up Complete (start CED-4a): January 2022
- ICSBEP Target (CED-4a): Fall 2022

Design Process

- Experiment design related to the 2019 ARCHIMEDES project
  - See the current LDRD EUCLID project for in-depth information
- Design Process:
  - Examine application Pu concentration ranges and associated Cl-35 (n,γ) sensitivities
    - Determine specific Pu concentration applications that cover concentration ranges
  - Develop multiple generic experimental benchmarks
    - Materials, geometries
    - Compare experimental benchmark designs to these applications (Cl-35 (n,γ) sensitivities, i.e. c_k and partial c_k)
    - Iterate on benchmark design
- Note: c_k and partial c_k are similarity coefficients that utilize model sensitivities to nuclear data and uncertainties associated with that nuclear data
  - What is the best way to determine if two models are “similar”?

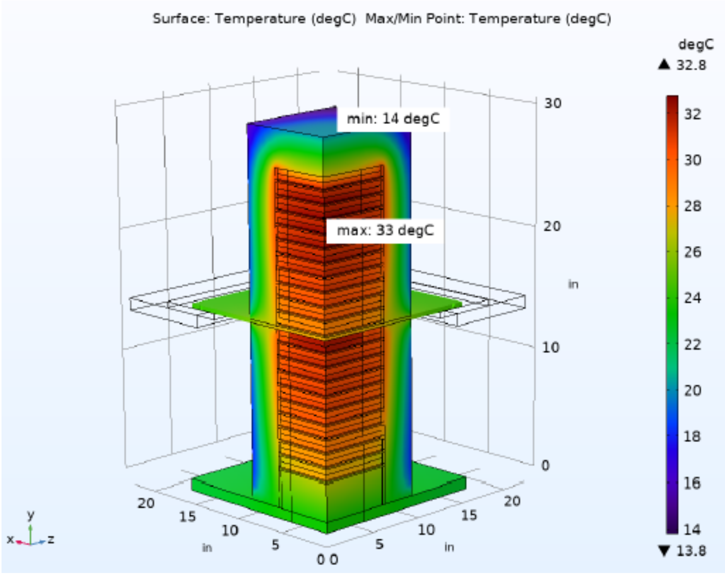
Gap Analysis (Comparison to Existing Benchmarks)

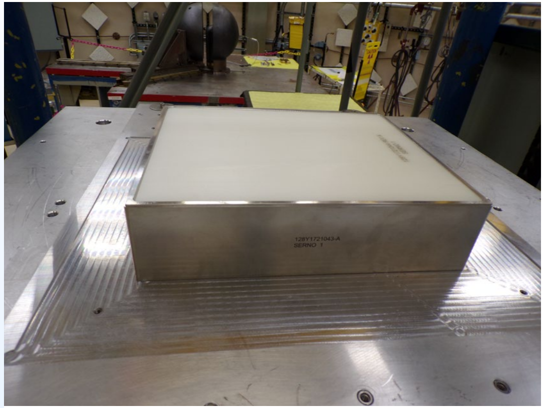




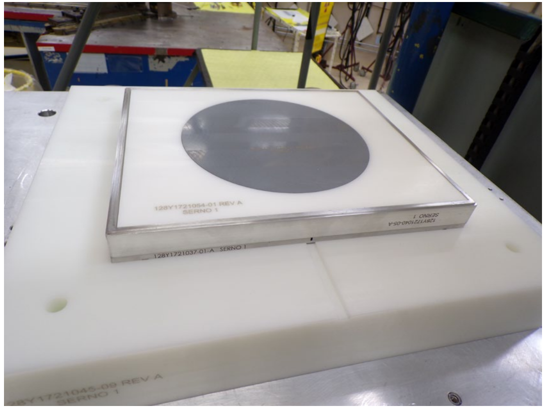
- A comparison to existing experiments was performed.
- Very few benchmarks sensitive to Cl-35 (n,γ) exist.
- The sensitivity of these benchmarks is much lower than the application.

Internal Heat Generation Consideration





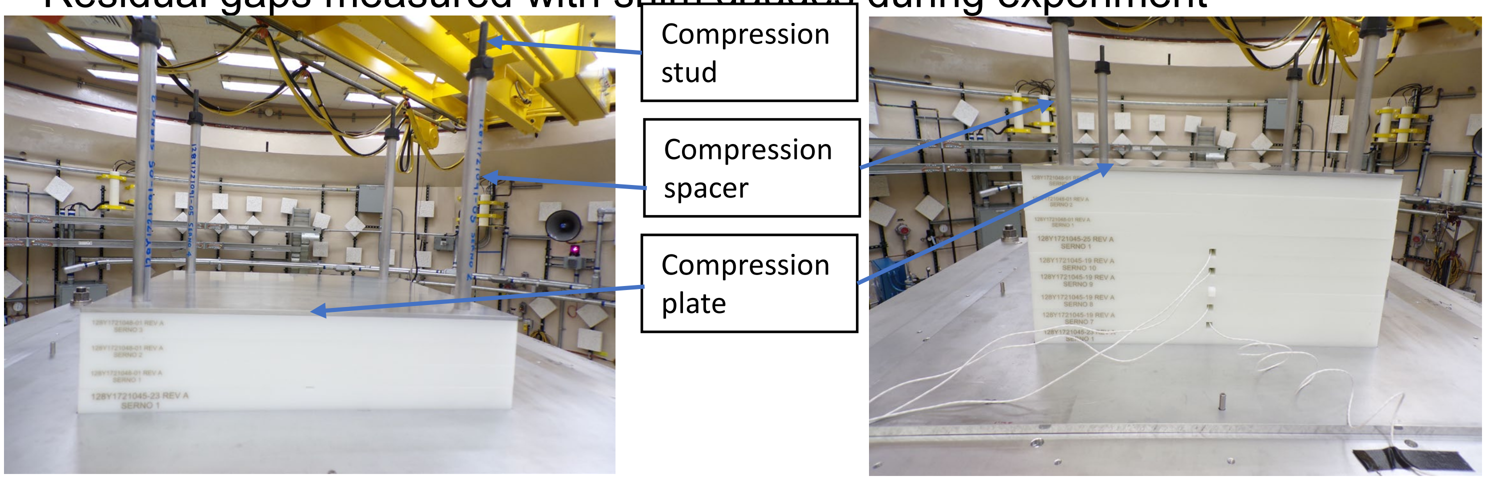
Base frame going to platen



Interlocking frame connection to tray and base frame

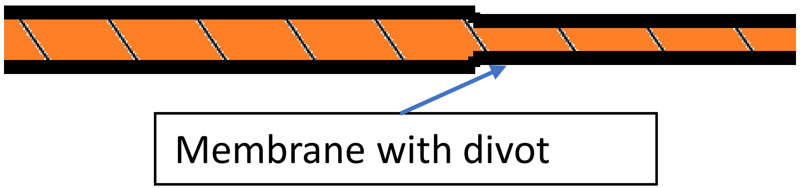
Gap Considerations

- Compression rods screw into membrane (very small thread length)
  - Compression spacers provide additional surface and separation distance of steel nut from assembly
- Compression plate, studs, spacers and nuts reduce gaps which cause significant neutron streaming paths in assembly
  - Residual gaps measured with shim gauges during experiment



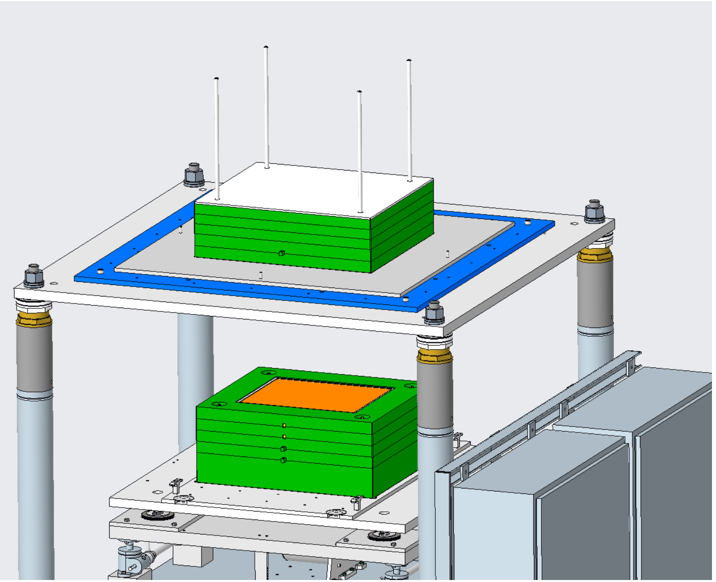
Lateral Gap Considerations

- For lateral gaps, the goal is to align the top and bottom stacks together with known uncertainties
  - Membrane has slight divot in top and bottom sides that the top and bottom stacks align into
  - Assured alignment by operating in LOCAL mode before starting remote approach
  - Imperfect alignment will cause reactivity loss, which is accentuated by the divot
  - Provides a visual indication of alignment from control room (through cameras)

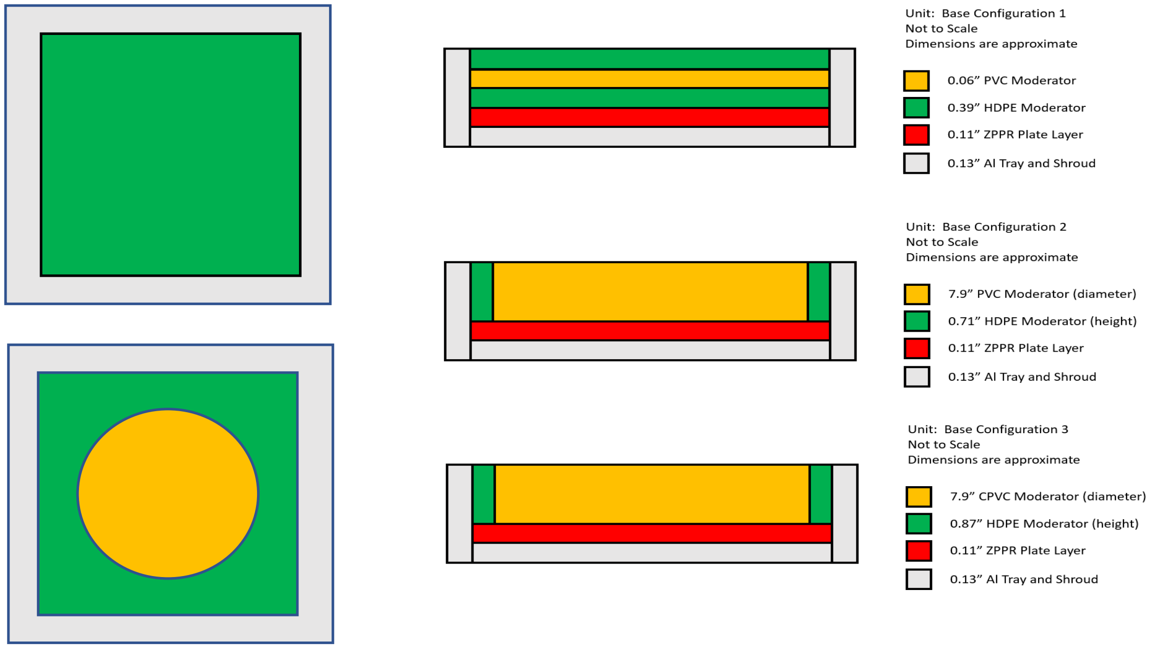


Final Designs

- Reflector: 3” HDPE (top, bottom, sides)
- Fuel: 5x4 (20 total per unit) ZPPR plates, ~105 g Pu per plate
- Moderator: HDPE (varying geometry)
- Cl Material: PVC or CPVC (varying geometry)
- Configurations:
  1. optimized for 30 g/L application (covers 20-100 g/L range)
     - Stack of HDPE-PVC-HDPE on ZPPR plates
  2. optimized for 300 g/L application (covers 300-400 g/L range)
     - ~7.9” diameter PVC cylinder inside HDPE on ZPPR plates
  3. optimized for 600 g/L application (covers 500-600 g/L range)
     - ~7.9” diameter CPVC cylinder inside HDPE on ZPPR plates



Final Designs



- Note that Al Tray and Al frame (shown in grey) is used to conduct heat out of assembly
  - For the top partial stack, “bottom” ZPPR tray (and shroud) sits directly on membrane/top stationary platform
  - For the bottom partial stack, the shroud goes through the bottom reflector and directly touches the platen

Results

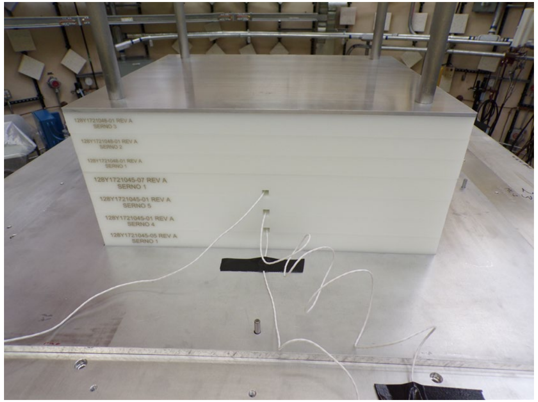
Measured Results

Configuration	Measured Reactor Period (seconds)	Associated Excess Reactivity (cents)	Maximum Observed ΔT (°C)
1	57.6	16.5	7.4
2	58.1	16.4	14.4
3	85.8	12.4	16.1

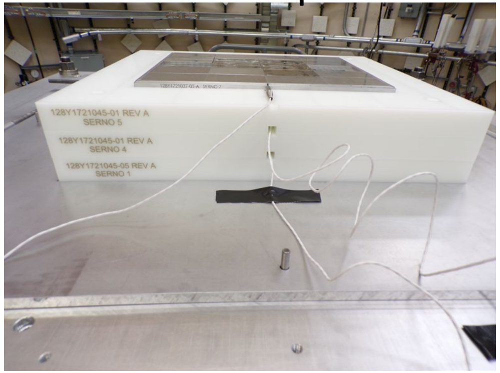
Configuration 1: 30 g/L

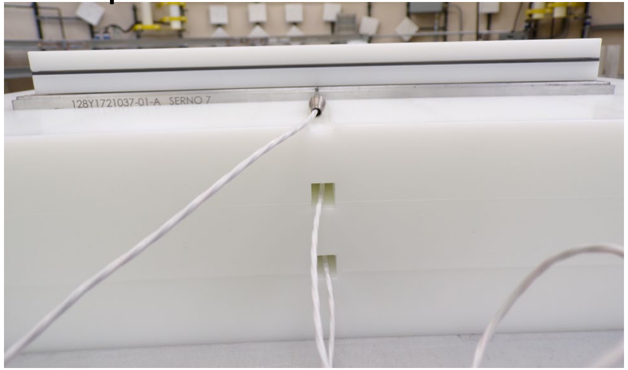
- Final configuration: 8 units
  - 4 full units on bottom (Pu units A-D)
  - 3 full units on top (Pu units E-H)
  - Partial unit on top of top (Al is aluminum plates nearly matching Pu plate dimensions)
  - RTDs
    - Every unit on bottom
    - Top three units on top

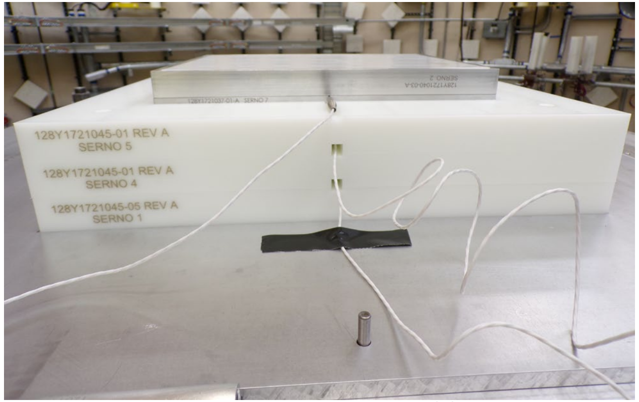
Configuration 1: 30 g/L



- Final configuration: 8 units
  - 4 full units on bottom (Pu units A-D)
  - 3 full units on top (Pu units E-H)
  - Partial unit on top of top (Al is aluminum plates nearly matching Pu plate dimensions)
  - RTDs
    - Every unit on bottom
    - Top three units on top



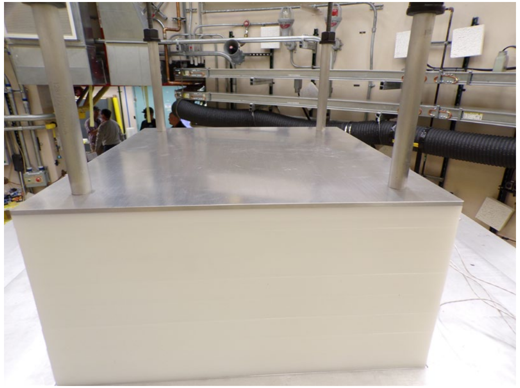


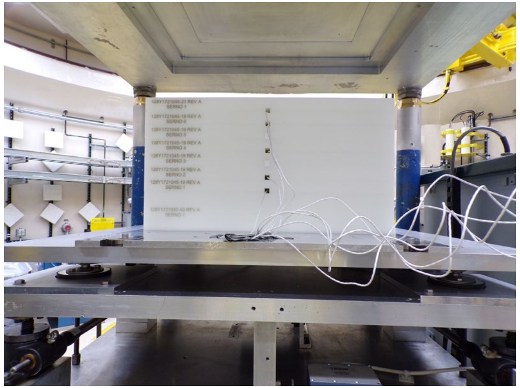


Configuration 2: 300 g/L

- Final configuration: 14 units
  - 7 full units on bottom (Pu units A-G)
  - 7 full units on top (Pu units H-O)
  - 0.875” top reflector (reduced from 3.000”)
  - RTDs
    - 5 of 7 units
    - 5 of 7 units

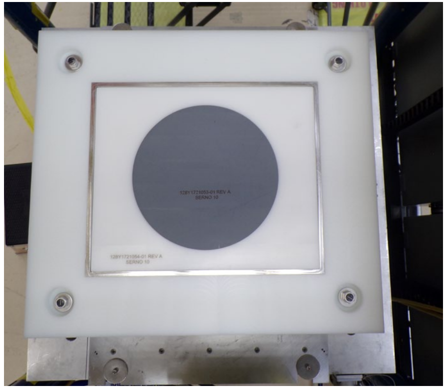
With and without side reflector

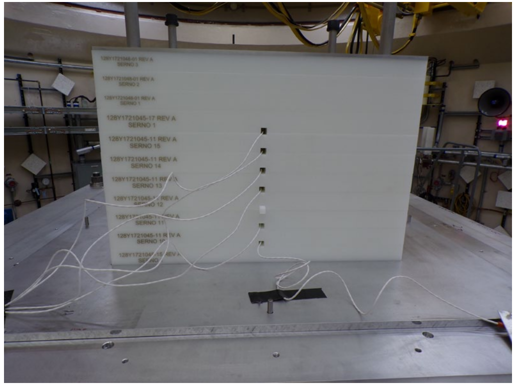


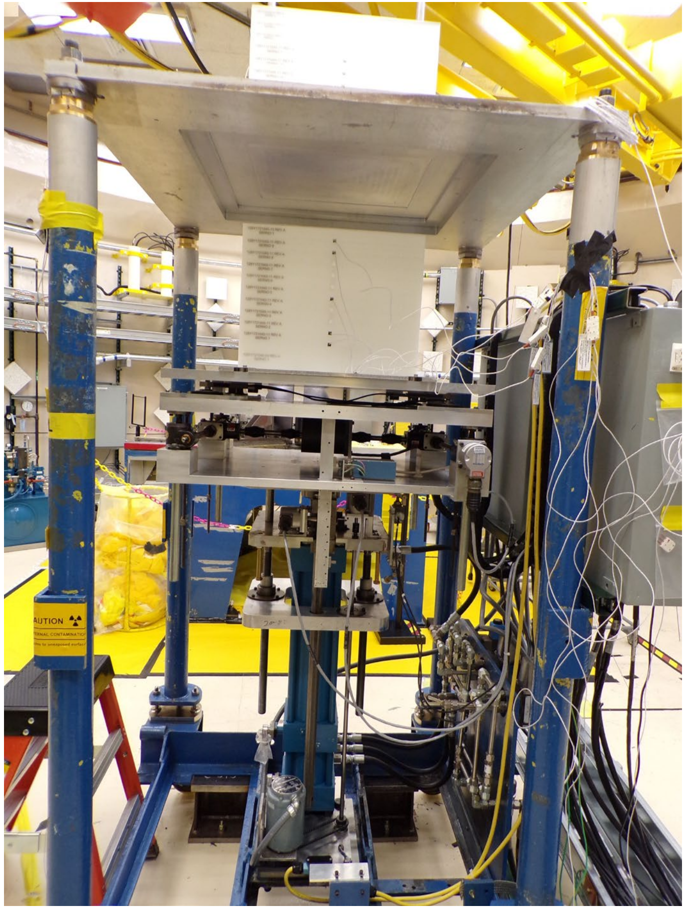


Configuration 3: 600 g/L

- Final configuration: 18 units
  - 10 full units on bottom (Pu units A-H)
  - 7 full units on top (Pu units K-R)
  - Partial unit on top of top (Al is aluminum plates nearly matching Pu plate dimensions)
  - RTDs
    - Top: 6 of 8 units
    - Bottom: 5 of 10 units

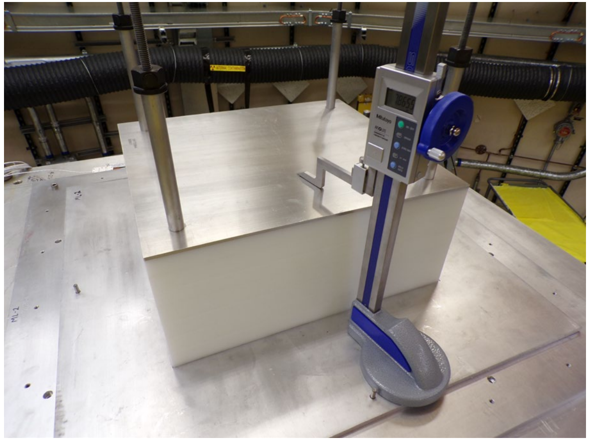






Physical Measurements

- Previous benchmark experiments have taught us a lot!
  - Many physical measurements required
  - Heights, gaps rotation, levelness
  - Samples of plastics received and sent out for detailed chemical analysis

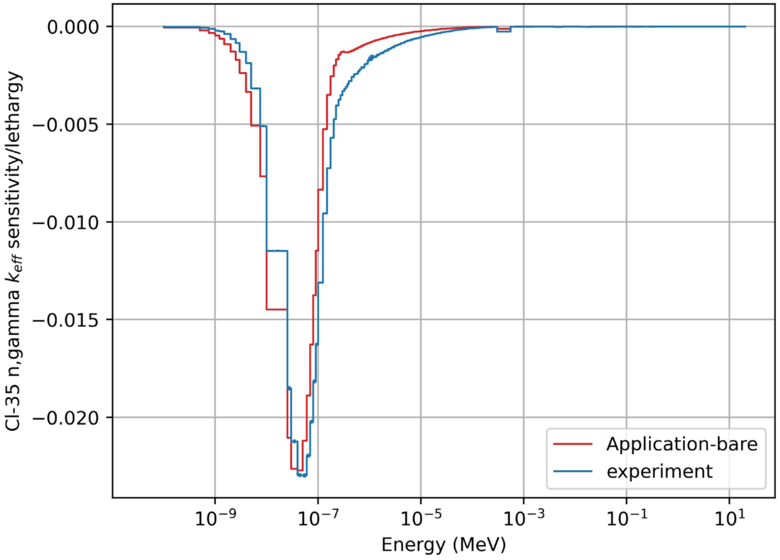


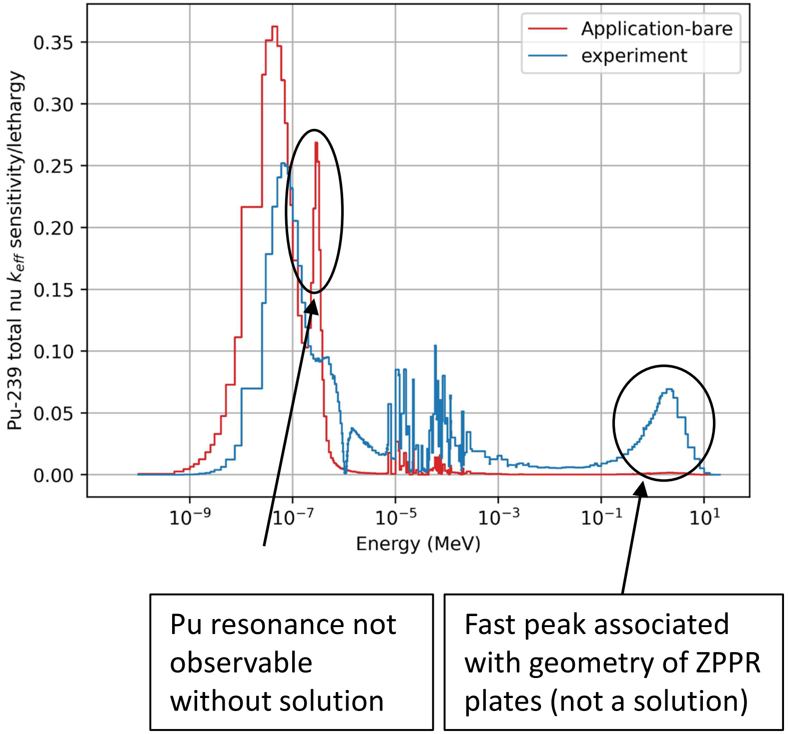
Preliminary Results

- Simplified MCNP geometry
  - Includes detailed Pu plates
  - Does not include gaps
  - Does not include detailed compositions

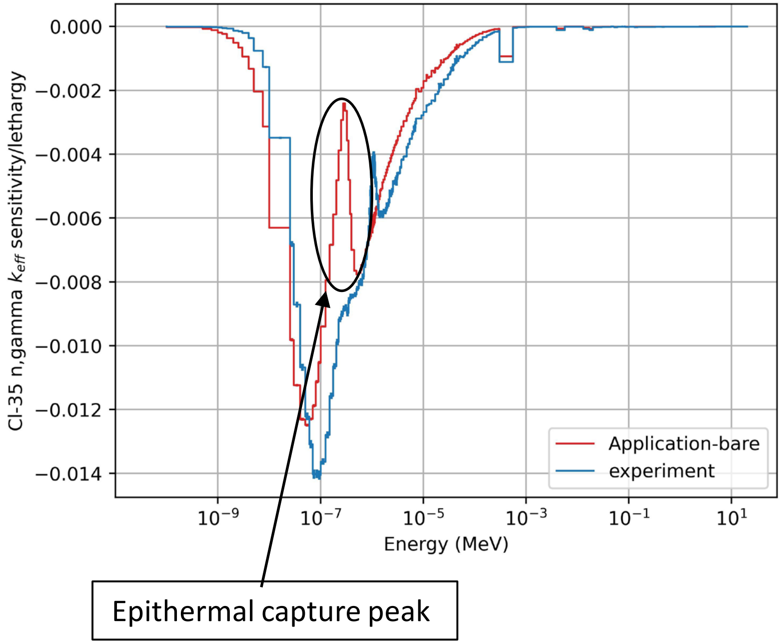
Configuration	Experiment	Calculated	Partial c_k Cl-35 capture
1	1.00035	1.00613	0.94 (30g/L)
2	1.00034	1.01211	0.99 (300 g/L)
3	1.00026	1.00199	0.99 (600 g/L)

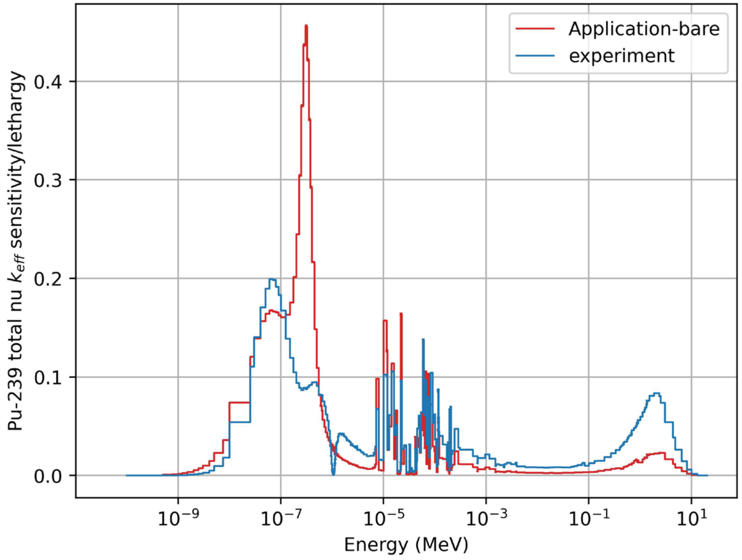
Sensitivity Plots: Configuration 1



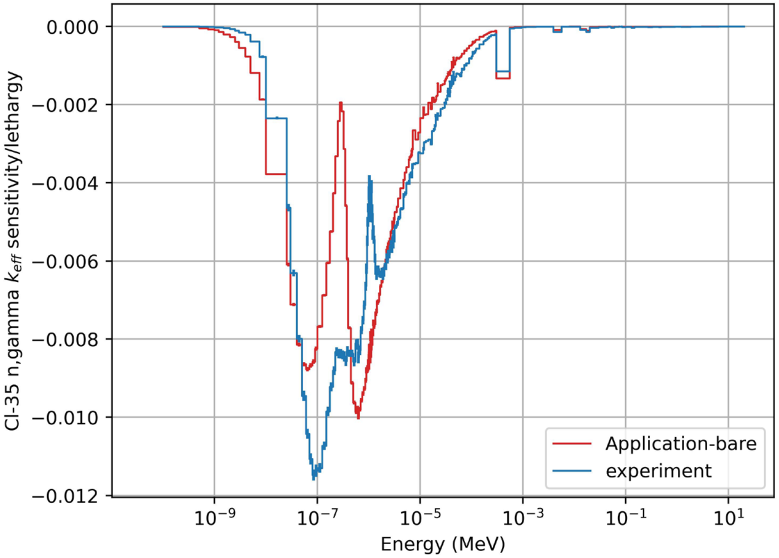


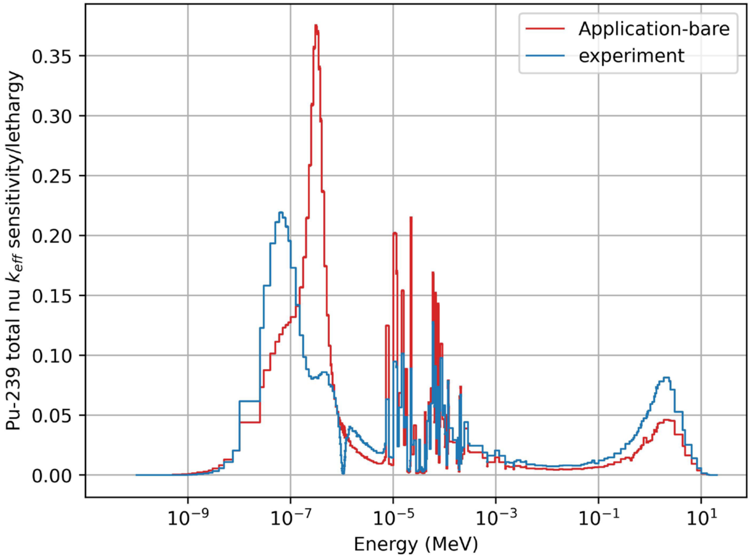
Sensitivity Plots: Configuration 2





Sensitivity Plots: Configuration 3





Future Work

- Draft ICSBEP benchmark (A LOT of work)
  - Target Fall 2022 Review Group Meeting, which means full completion by August 2022
  - Poly, PVC, CPVC chemical analysis
    - Received samples with parts
    - Requests out to companies for quotes; usual company no longer doing full analysis
  - Evaluate measurement uncertainty
  - Detailed (very detailed) MCNP model
  - Section 1 rough draft complete

Operational Support

- Aqueous Chloride Operations Personnel Attended 2nd week
  - Supervisor, process engineers, operators
  - Participated in 1/M process
  - Loaded fuel
  - Felt PERSONALLY connected to the work

Acknowledgements

- This work was supported by the Plutonium Program Office (NA-191) under Office of Production Modernization (NA-19), funded and managed by the National Nuclear Security Administration for the Department of Energy
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